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HUNTSVILLE, ALABAMA

A RADIANT HEAT SOURCE IN A SIMULATED ALTITUDE ENVIRONMENT

By

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ABSTRACT

This report discusses a radiant heating device. The device has met successfully the goals established at the initiation of the development which are listed as follows:

a. Develop radiant heat fluxes up to 100 BTU/ft^2-sec.

b. Concurrent with the generation of these heat fluxes, simulate the environments to which a launch vehicle is exposed during ground and flight testing. This is to include vibration and pressure.

c. Be capable of operating for times in excess of 5 minutes.

d. Be fully instrumented to record automatically heat flux, pressure, and specimen temperatures.

The detailed development steps are discussed, and the device design is described.

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ENGINEERING MATERIALS BRANCH
PROPULSION AND VEHICLE ENGINEERING DIVISION

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SUMMARY

A thorough investigation of the work covered by this report will lead to the following conclusions:

1. This device can provide radiant thermal energy, to a large black body receiver, of up to 80 BTU/ft^2-sec., or down to less than 10 BTU/ft^2-sec.

2. The heat flux can be pre-set and controlled within plus or minus 2 BTU/ft^2-sec. on moderate programming requirements.

3. Environmental pressure can be simulated to an altitude of about 130,000 feet.

4. Operational test time is virtually unlimited at lower heat fluxes. One test of more than seven minutes at 30 BTU/ft^2-sec. has been made.

INTRODUCTION

In August 1961, a concentrated effort was initiated to develop a device which could generate a high radiant heat flux in a simulated altitude environment. The device was to: (a) develop radiant heat fluxes up to 100 BTU/ft^2-sec; (b) simultaneously with (a) simulate the environments to which the base of a launch vehicle is exposed during ground and flight testing, including vibration and environmental pressure; (c) be capable of operating continuously for more than five minutes; and (d) be fully instrumented to record automatically, heat flux, environmental pressure, and specimen temperatures.

The General Electric T-3 1000 watt quartz infrared lamps have been used extensively in this branch to achieve radiant heating of the order of 25 BTU/ft^2-sec. At this heat flux, and testing a "clean" (non-gassing) material, the lamp life was quite good. However, if during testing, material was expelled into the lamps and adhered to them, the useful life became quite short, perhaps as short as 120-130 seconds. Also, the reflector, mounted immediately behind the lamps, had to be removed for cleaning after 2 or 3 tests of "dirty" materials. Others have used the 2000 watt T-3 lamps to achieve heat fluxes of 40 BTU/ft^2-sec. consistently, and up to 60 BTU/ft^2 sec. briefly for special purposes. In these cases, the tube life was reasonable at 40 BTU/ft^2-sec., but at higher levels it became quite short. In some of the tests on materials, several of the lamps would fail during the test, thereby reducing the confidence which could be placed in the test results. Another shortcoming of the lamps is that the 650°F temperature limit at the electrode seals controls the test duration at considerably less than five minutes. Because of these factors, quartz lamps were believed to be inappropriate for achieving heat fluxes of 100 BTU/ft^2 sec.

Considerable effort was devoted to the development of an electric arc heated radiator. The simplest arc heated radiator (FIG 1) consisted of a truncated wedge with the electrodes located equidistant from each graphite plate which formed the wedge. This geometry resulted in an area of intense radiation that was too small to be of practical value. A thin, flat, graphite plate was placed above the arc in an attempt to diffuse the heat into a larger area at reduced radiant intensity. This was partially successful; however, the refractory plates at the end of the radiator, installed for thermal protection of the arc housing, eroded away rapidly.

The next attempt at an arc heated radiator is shown in FIG 2. This consisted of one fixed and one movable electrode surrounded by an insulated graphite tube. This scheme offered certain advantages over the previous system, such as improved life of various parts.

INTRODUCTION (CONT)

Both of these systems produced a heat flux of approximately 75 BTU/ft^2-sec. with a 40 KVA welding transformer. Two disadvantages of this latter system made it undesirable; first, an excessively long time was required for the device to reach maximum heating (as much as 15 minutes), and second, and most important, the high temperature plasma from the arc melted the refractory insulation (JM-3000 brick) around the graphite tube, causing locking of the movable electrode by carbide formation. The latter difficulty was reduced, but not eliminated, by installing a graphite sleeve around the movable electrode, which protruded several inches beyond the insulating brick, and by insulating the brick with carbon black. See FIG. 3. The basic limitation of this system was that the plasma became so conductive that sufficient power could not be developed to make the system operate at extremely high heat fluxes. A second problem was that the entire radiator area never reached a uniform temperature.

Concurrent with the testing of the arc heated radiators was a reduced effort using resistance heated radiators. The first one tested (Fig. 4) was a spiral, cut from a graphite tube. Due to poor thermal conductivity across the electrical joint, the temperature reached was relatively low. The heat flux was 19 BTU/ft^2-sec. However, the tube became hot very quickly, showing there was promise in this method.

A second radiator was designed in the shape of a flat spiral electrode mounted in a tube filled with carbon black as shown in FIG 5. Considerable difficulty was experienced from arcing across the electrodes at high radiator temperatures. When operating properly, however, a heat flux of 77 BTU/ft^2-sec. was achieved. At best, run times were very short.

A third radiator, shown in FIG 6, utilized a graphite block cut from first one side and then another to form an accordion-type electrode. The major change from the previous radiator was that the electrical contacts were on opposite ends of the radiator, rather than one being in the center and one on the outer edge. The new radiator was mounted in a "Transite" box, which was insulated with insulating brick, carbon black, and graphite. The first test with this radiator, made in air, produced a heat flux of 95 BTU/ft^2-sec. on a black body calorimeter. Modifications of the furnace included reducing the thickness of the graphite insulation plates, and replacing the carbon black, first, with silicon carbide, and later with charcoal, both ground and tubular The final version of this furnace had ¼ inch thick graphite insulation plates, with powdered charcoal in the bottom. The charcoal was held down by several layers of graphite cloth with strips of graphite around the edges. All except the last modification produced a reddish-blue haze and/or serious outgassing. The final arrangement produced the

INTRODUCTION (CONT)

least haze and no outgassing.

The current design of the radiator is shown in FIG 7. In this design, the "Transite" box and its various insulations are replaced by a water-cooled, gold-plated metal reflector. The first model, ceramic gold on stainless steel, was unsuccessful, but the next attempt, using gold electroplated on copper, was most successful. One additional improvement of considerable importance was the installation of a radiation pyrometer behind the reflector body, thus giving automatic monitoring of the radiator temperature.

TEST SETUP

The completed device, shown in FIG 8, includes the environmental chamber, sample holder, protective shield, radiator, movable mount for radiator, control console, recorders, filters for vacuum pump, and line to vacuum pump.

The environmental chamber is five feet in diameter and five feet high, has two doors, two feet by four feet, and seven windows, each six inches square. The cover contains a 24 inch square access hatch. All openings are sealed with rubber gaskets. Included in the tank wall is a valve with which the atmosphere inside the chamber can be maintained at any desired composition and pressure above the blank-off pressure of the pump. The blank-off pressure of the pump alone is 0.60 mm Hg, and that with the tank in the system is 1.00 mm Hg. The windows are covered with one-half inch of pyrex, and they can be used for mounting various devices, such as the vibration mechanism.

The sample holder is gold-electroplated copper, water-cooled, with a cut-out six inches square for the samples. This plate is mounted on a rod supported by ball bearings at the top and attached to a source of vibration at the bottom. The vibrator is an eccentric, connected through a variable speed pully to an electric motor. As adjusted presently, the center of the sample experiences a vibration of about 11g at 30 cycles per second, with a double amplitude displacement of one-fourth inch.

The protective shield also is composed of gold-electroplated copper which is water-cooled. This plate is mounted on a pivot rod and is moved in and out of the protective position by a double acting pneumatic cylinder. The removal and replacement of this shield determines the time the sample is exposed to the radiant heat.

The radiator is approximately six inches square and includes the last design described in Section 2 of this report. The power source used is a 40 KVA welding transformer.

The movable mount for the radiator is a hand-operated, screw-driven rack, mounted on appropriate slides, with a maximum movement of 8 inches. If the need should arise, this could be motor-driven for additional versatility in programming the heat flux of the furnace.

The control console is designed for complete operation of all components in the test device. Automatic recordings of amperage and voltage are made for each test operation. Power regulation can be programmed automatically, thus permitting the heat flux to the test sample to be varied according to a pre-determined curve. The temperature recorders mounted in the console have capacity for six thermocouples (or other millivoltage sources) by proper use of switches. The chart drive motors are operated automatically by the shield actuation switch. The recorders are provided with a time synchronization marking system. The reduced pressure capability of the device is provided by a high capacity vacuum pump (140 cubic feet per minute). To protect the pump, coarse, medium, and fine screen filters, mounted on a water-cooled trap, are included between the pump and test chamber. In addition, provisions have been made to permit gas samples from the line to be extracted for analysis to determine the outgassing constituents of test samples. The maximum reduced pressure capability of the system is of the order of 1 mm Hg.

TEST RESULTS AND DISCUSSIONS

Approximately 100 calorimeter runs have been made. These have been made in air, nitrogen and vacuum. In each case, a radiation pyrometer reading, a theoretical form factor, a temperature rise rate, and the atmospheric environment have been recorded. FIG 9 shows the correlation of heat flux as measured with the calorimeter wi.h that calculated from the radiation pyrometer temperature measurement.

Calibration of the radiator was accomplished as follows:

1. The surface temperature was measured by a radiation pyrometer using the conversion chart furnished by the manufacturer.

2. The total emittance was calculated from the Stefan-Boltzmann Law, $W = \sigma T^4$. W is total black-body radiant emittance, watts/cm^2; σ is the Stefan-Boltzmann constant, 5.673 X 10^{12} watt/(cm^2) (deg.^{4}); T is the surface temperature, degrees K. The emissivity of the radiator was assumed to be unity.

3. The radiant energy units were converted to BTU/ft^2-sec. using the relationship, 1 BTU/ft^2-sec. = 0.8811 watts/cm^2.

4. A "form factor" (F) was determined from the equation

$$F = \frac{1 + B^2 + C^2 - \sqrt{(1+B^2+C^2)^2 - 4\ B^2C^2}}{2B^2}$$

in which: B = radius of the calorimeter divided by distance between radiator and calorimeter.

C = radius of radiator divided by distance between radiator and calorimeter.

The effective radius of the radiator, which was essentially square, was established by determining the area, dividing by π, and extracting the square root. For most of the testing "F" = 0.68.

5. The heat flux received by the calorimeter was calculated from the equation,

$$q = \rho \sigma C_p \frac{dT}{dt}$$

in which q is the heat flux, BTU/ft^2-sec.

ρ is the density, lb/cu. ft.

σ is emissivity, dimensionless, assumed unity

Cp is specific heat, BTU/lb.

$\frac{dT}{dt}$ is time rate of temperature change.

6. The radiant emittance (W) multiplied by the form factor (F) is plotted as the abscissas and the heat flux received by the calorimeter; q, is plotted as the ordinate in FIG 9. This theoretical line equates the heat flux emitted to that received.

It will be observed in FIG 9 that the correlation of actual (measured) to theoretical heat flux in vacuum is excellent, while that in air and in nitrogen leaves something to be desired. The most logical explanation for the discrepancies is convective cooling by the flow of "cool" gas over the surface of the calorimeter caused by the formation of currents in the chamber during testing. This is based on the observation of serious erosion on the lower, forward edge of the radiator after a run in either air or nitrogen. This explanation has been verified by using a quartz shield in front of the calorimeter to block out convective cooling. With the shield in place, the actual heat flux in air agrees with that in vacuum and with the theoretical calculations. No indication of radiator erosion from convective gas flow has been noted in the vacuum tests.

The discrepancies mentioned above do not invalidate the use of the equipment in any environment. They only verify the need for calibration of the equipment for the particular environment to be used. A correlation curve can then be drawn for the heat flux measured by the calorimeter and that calculated from radiation pyrometer readings. This curve provides the necessary correction factor. Such a curve has been made for air and nitrogen atmospheres.

Many samples of material have been tested on this device. The results of these tests will be included in future reports.

FUTURE WORK ON THIS PROGRAM

The continuation of this program is planned as follows:

1. The power source is to be increased from the present 40 KVA welding transformer to a 500 KVA variable reactor.

2. The pumping capacity is to be increased to simulate an altitude of 240,000 feet or more.

3. The feasibility of adding a convective heating capability is being studied.

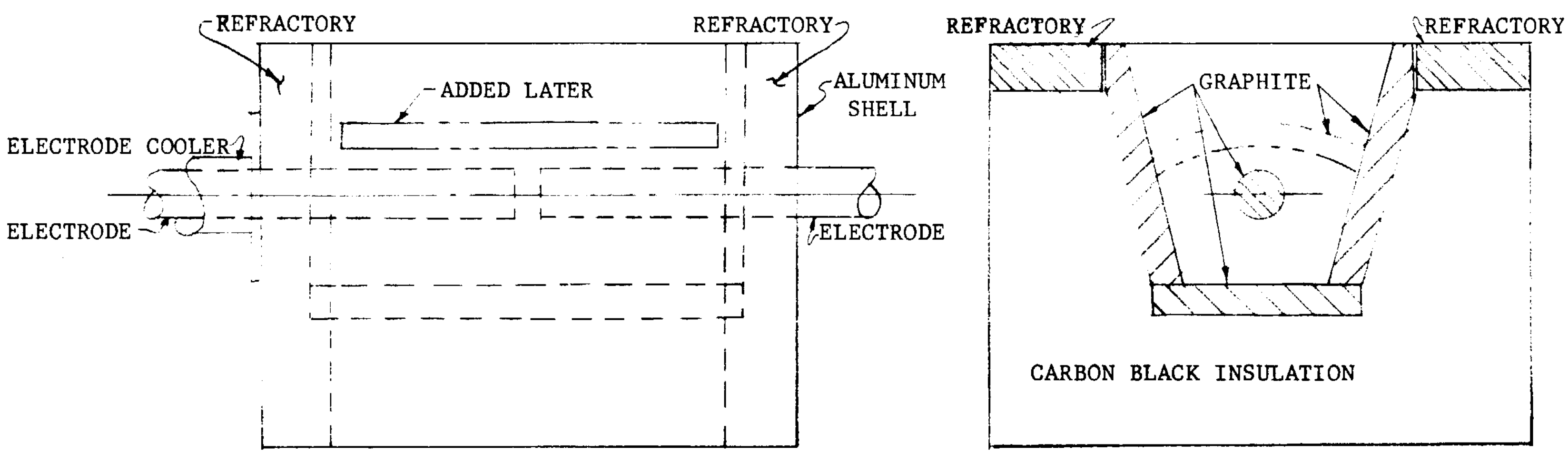

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FIGURE 1. INITIAL ARC-HEATED RADIATOR DESIGN

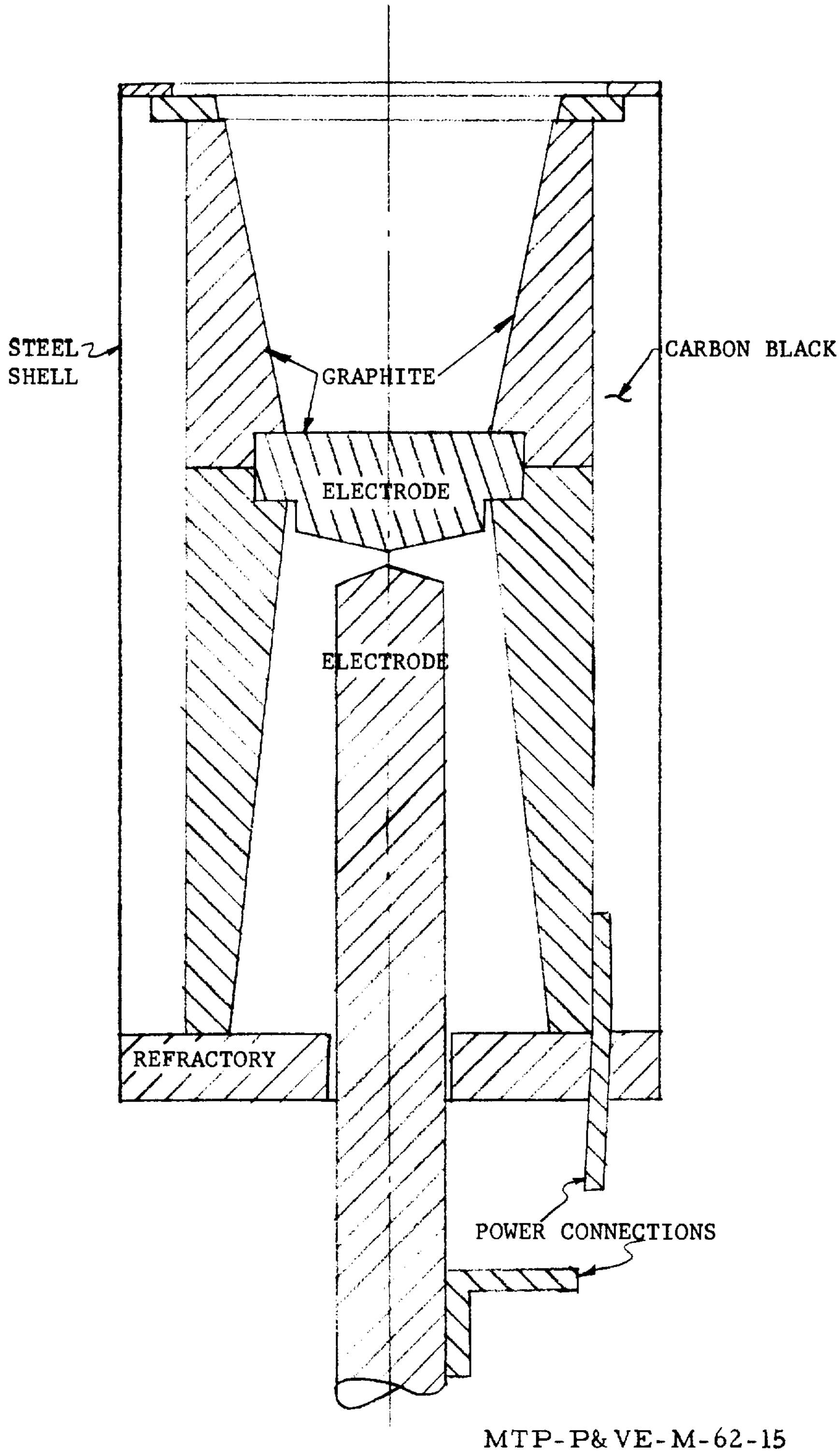

FIGURE 2. TUBULAR ARC-HEATED RADIATOR

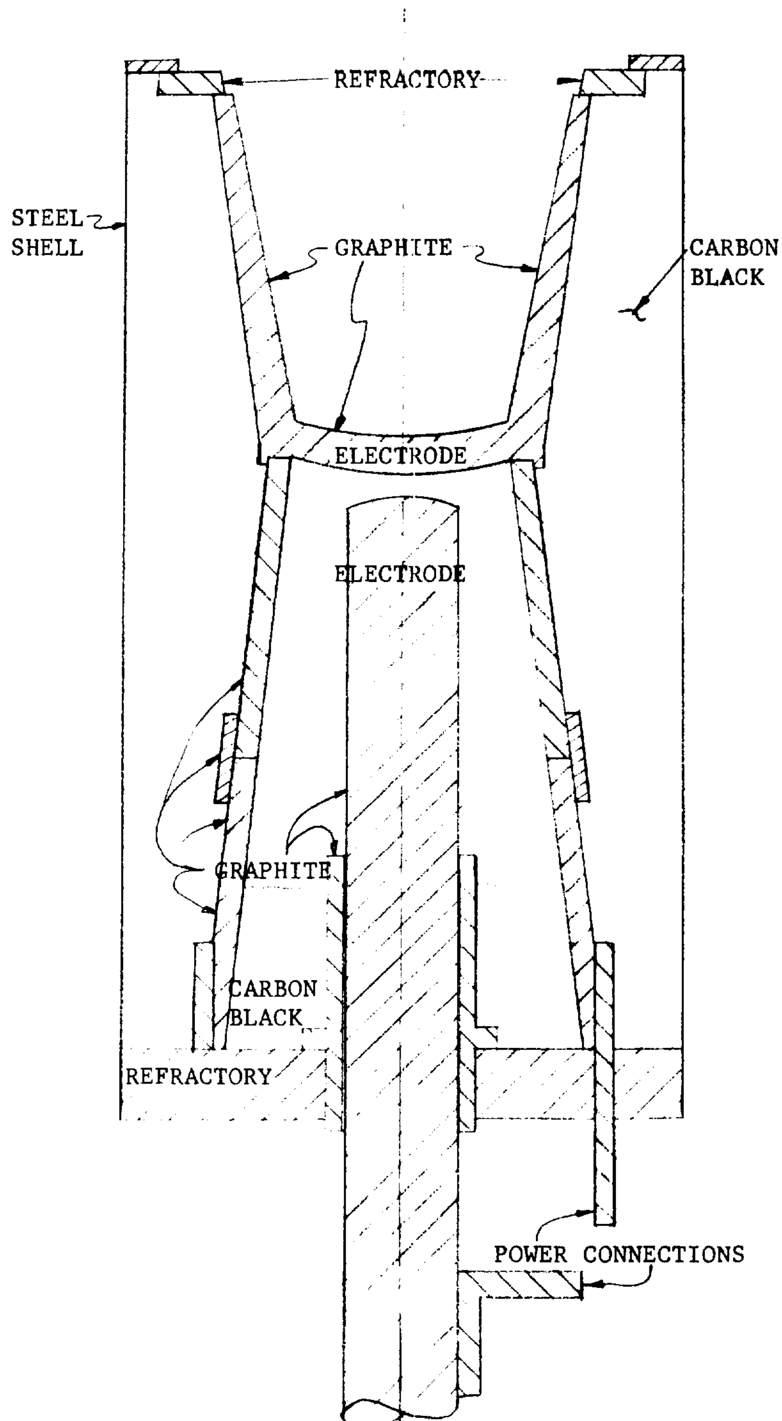

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FIGURE 3. TUBULAR ARC-HEATED RADIATOR WITH FINAL MODIFICATIONS

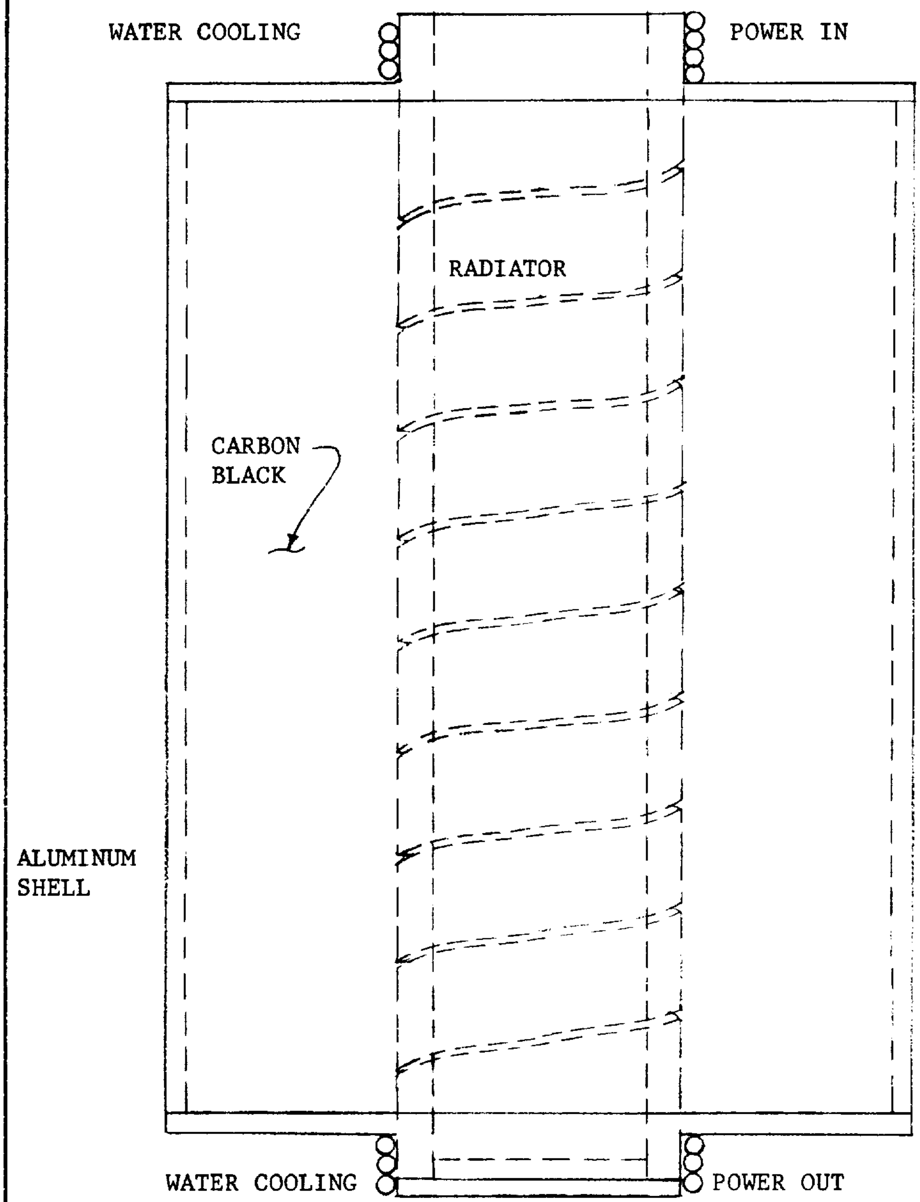

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FIGURE 4. RESISTANCE HEATED RADIATOR (SPIRAL TUBE)

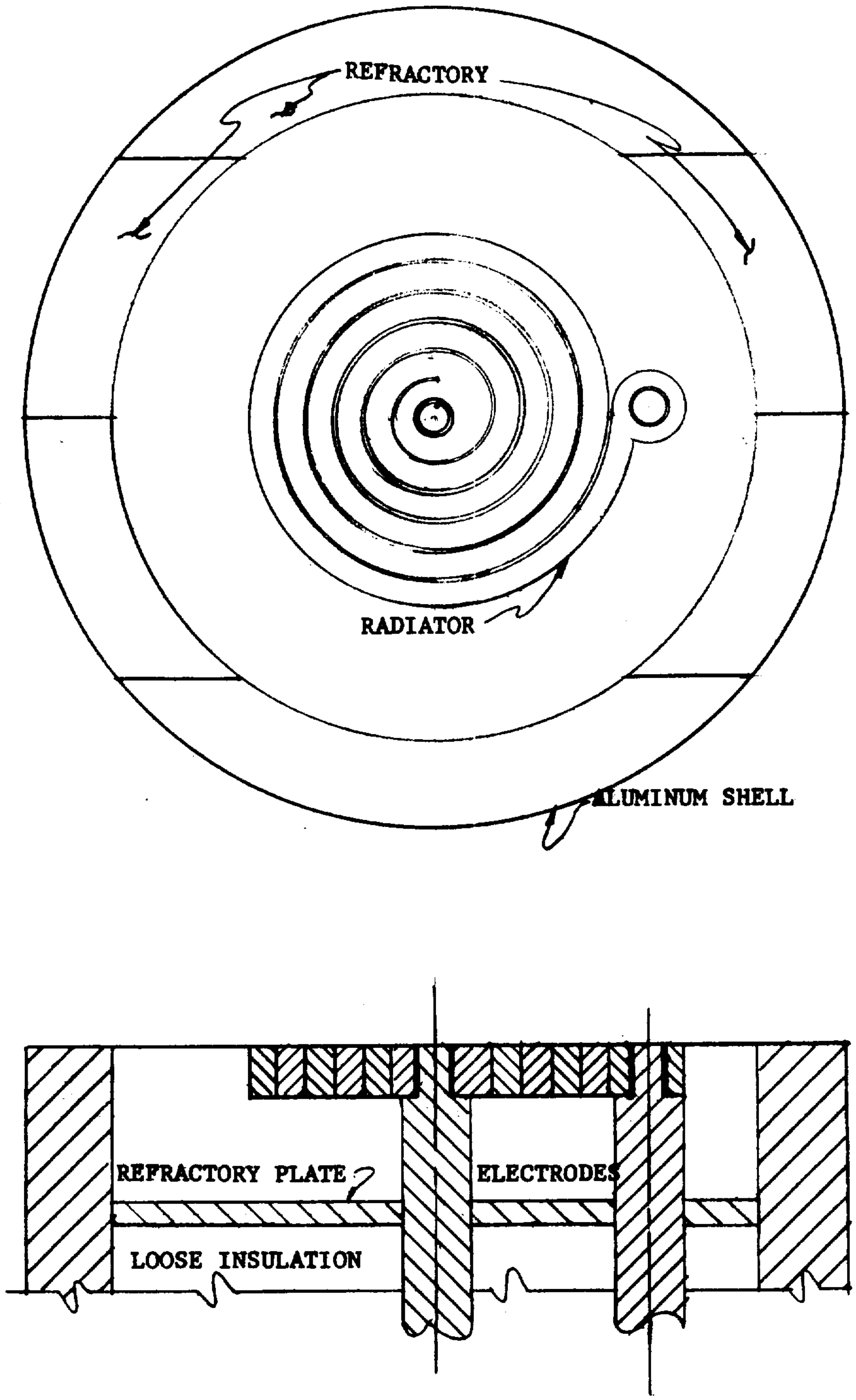

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FIGURE 5. RESISTANCE HEATED RADIATOR (FLAT SPIRAL)

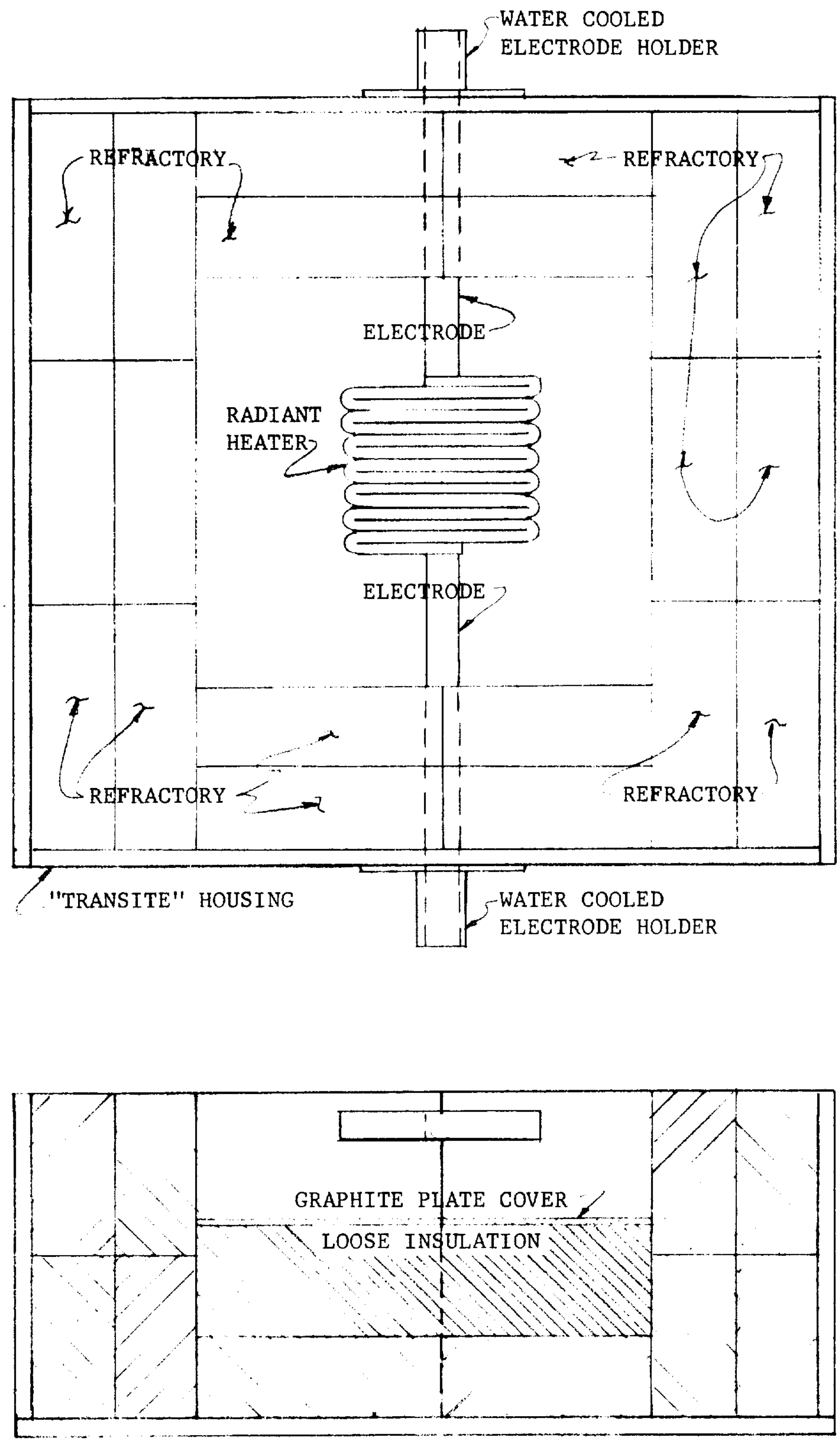

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FIGURE 6. RESISTANCE HEATED RADIATOR (ACCORDION) IN "TRANSITE" BOX

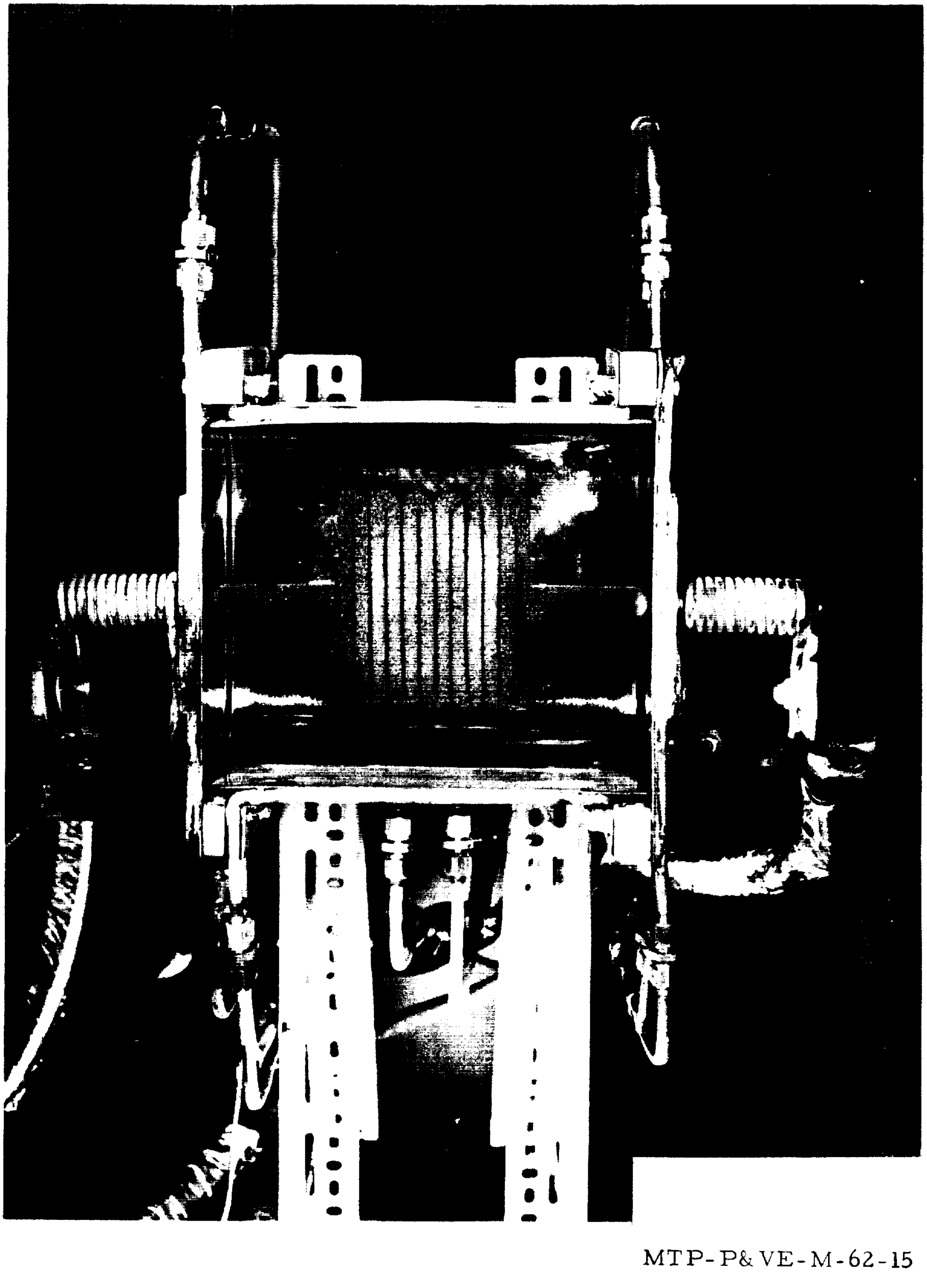

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FIGURE 7 - RESISTANCE HEATED RADIATOR IN WATER-COOLED COPPER

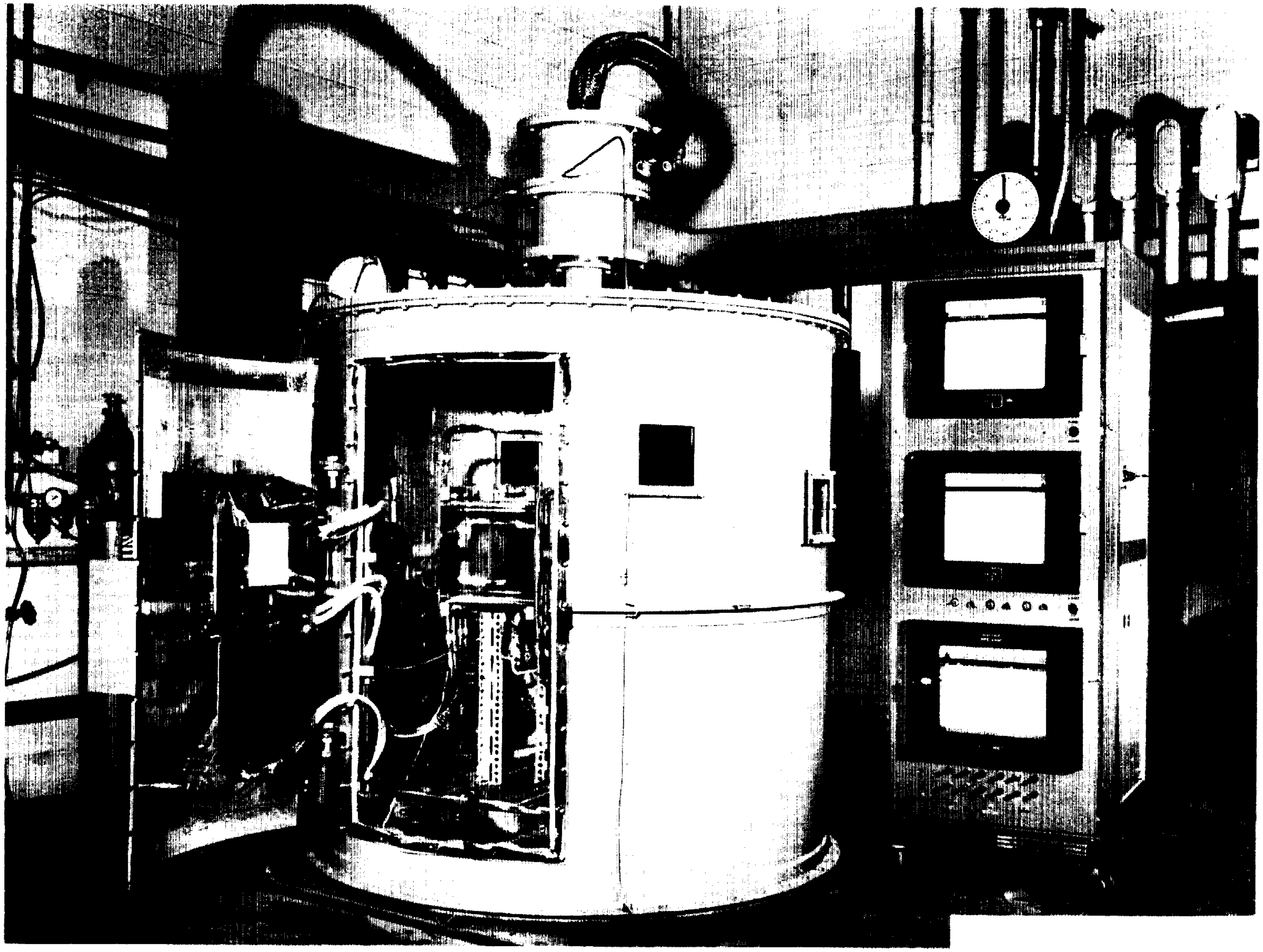

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FIGURE 8 - TEST SETUP

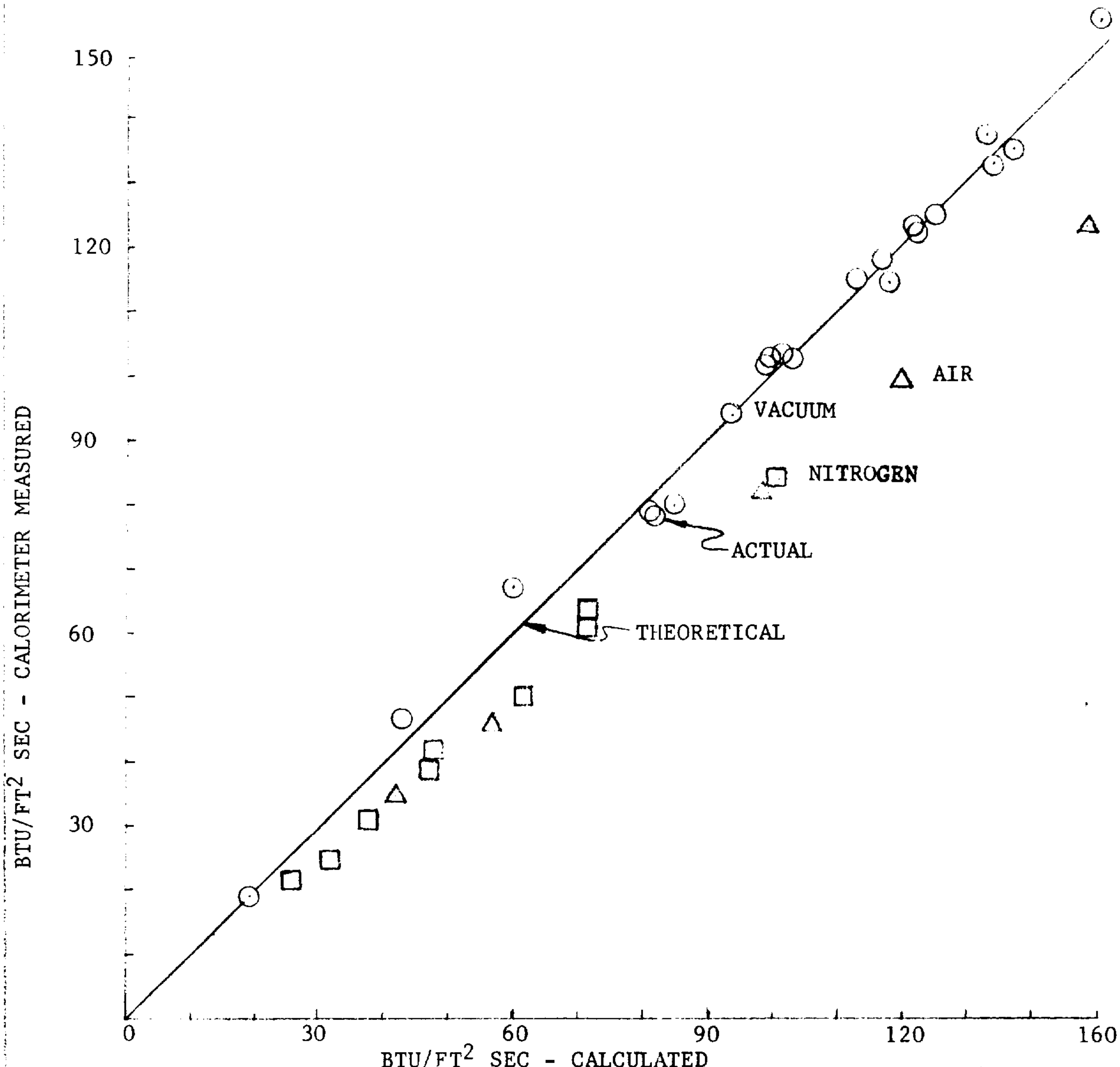

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FIGURE 9 - CORRELATION OF HEAT FLUX, MEASURED VS CALCULATED

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2. Jacob, Max, Heat Transfer, John Wiley and Sons, 1957, Volume 2, Page 14.

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The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

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